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Acute Effects of Parallel Back Squat Performed in Different Set Configurations on Neuromuscular Performance

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1 **Acute effects of different resistance training configurations on neuromuscular performance**

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14

15 **Abstract**

16 We compared the acute effects of parallel back squat performed from different resistance training
17 configurations on neuromuscular performance. Twenty-eight young adults underwent the four
18 experimental conditions: inter-repetition rest, traditional, traditional to failure, and rest-pause in the
19 parallel back squat in a randomized, counterbalanced, and cross-over design. The neuromuscular
20 performance was assessed through peak torque of knee extensors and flexors at two angular velocities
21 (90 and 120°/s) in three moments (before, post, and post-30 min). The peak torque of the knee extensors
22 and flexors at 90 and 120°/s decreased immediately after training for traditional, traditional to failure,
23 and rest-pause (-8.1% to -17.7%, $P < .001$). A greater reduction in the extensor peak torque was found
24 at 120°/s ($P < .05$) in the rest-pause (-17.7%) when compared to traditional (-10.8%). The peak torque
25 returned to baseline values only at post-30 min for the traditional configuration for the knee flexion
26 action at 120°/s. The peak torque remained similar for the muscular actions and angular velocities for
27 the inter-repetition rest ($P > .05$). Our results suggest the inter-repetition rest configuration seems to
28 be a more appropriate strategy for maintaining the lower limb neuromuscular performance after a
29 resistance training session.

30

31 **Keywords:** peak torque, neuromuscular fatigue, isokinetic strength, strength training, resistance
32 training systems, force.

33

34 **Introduction**

35 Resistance training is characterized by a systematic organization and manipulation of
36 prescription variables (external load, number of repetitions, muscle action velocity, and rest intervals
37 between sets), adjusted according to each training session objective [1-3]. In this context, some set
38 configurations have been adopted to mitigate the reduction in neuromuscular performance, with the
39 premise of optimizing short- and long-term muscular adaptations [4, 5]. For example, recovery
40 intervals between a block of repetitions or between each repetition—which characterizes two types of
41 cluster-set configurations—seem to be an effective strategy to increase the volume-load without a
42 substantial reduction of velocity and power output throughout a set [4]. On the other hand, there is
43 another possible cluster-set configuration that has been widely used is the rest-pause (RP) [6, 7]; in
44 this case, the rest is given only after the practitioner reaches voluntary muscle failure (i.e., inability to
45 complete a repetition with a full range of motion) [6, 8].

46 In this regard, a recent systematic review with meta-analysis [4] demonstrated that intra-set rest
47 and inter-repetition rest (IRR) configurations (both not to muscle failure) allow the maintenance of
48 muscle action velocity and power output when compared to traditional (TRD) configuration during
49 and post-exercise. On the other hand, the insertion of rest intervals after voluntary muscle failure seems
50 ineffective in preserving performance in the RP [4], likely because of the accumulated fatigue.
51 However, the only study that compared the RP with other set configurations, and that was included in
52 the meta-analysis, found similar reductions in force output between two different training
53 configurations (RP and IRR) after 20 repetitions of squats with equalized volume-load [6]. Also, five
54 minutes following the end of the session, the force output had returned to the pre-training values,
55 suggesting that the RP maintains force output when protocols with a low number of repetitions or
56 volume are performed. In addition, since practitioners often perform a high volume (i.e., a higher
57 number of repetitions), and this strategy potentially induce higher acute reductions in neuromuscular
58 performance, it is necessary to investigate set configurations that attenuate this impairment.

59 About RT volume, different systematic reviews with meta-analysis have suggested that higher
60 training dose may induce significant neuromuscular adaptations and performance improvements in
61 young and older adults [9, 10]. Therefore, the analysis of the effects of different resistance training
62 configurations (e.g., IRR, RP, TRD) with a higher number of repetitions may support the prescription
63 of such set structures to perform a higher amount of work with less or without impairment of
64 neuromuscular performance. Furthermore, depending on exercise choice, different muscles will
65 experience different magnitudes of acutely reduced force output and muscle damage [8, 11]. For
66 example, when performing the squat, trained subjects experienced severe muscle damage in the
67 quadriceps [11]. However, we do not have an accurate description of the effects of this exercise on the
68 neuromuscular function of the other muscles that participate in the hip and knee extension movement
69 (i.e., hamstrings) and the effect of different set configurations.

70 Therefore, given the scenario described above, the present study aimed to compare the acute
71 effects (immediately after and post-30 min) of the parallel back squat performed from different
72 resistance training configurations on neuromuscular performance. Besides, we tested whether there
73 are differences in the force output of the extensors versus knee flexors after each experimental
74 protocol. Our initial hypotheses are i) the IRR and TRD induce reductions of small magnitude when
75 compared to TRD-F and RP configurations; ii) the performance is restored under all circumstances
76 after 30 min of the training session; and iii) the fatigue induced by TRD-F and RP configurations
77 immediately after a training session is higher in the extensors than in the knee flexors after the parallel
78 back squat exercise.

79 **Materials and Methods**

80 **Study design**

81 A randomized, counterbalanced, and cross-over study with four experimental conditions was
82 carried over four weeks, with a seven-day washout between each one. The sample was composed of
83 trained young adults with experience in the parallel squat exercise from the following resistance

84 training configurations: inter-repetition rest (IRR), traditional set without concentric muscle failure
85 (TRD), traditional to muscle failure (TRD-F), and rest-pause (RP). The participants made seven visits
86 to the laboratory. The first visit was intended to familiarize participants with the procedures and to
87 sign the informed consent form. The second and third visits were designed to perform the test and
88 retest of 15 repetitions maximum (15RM) and measure the knee extensors' peak torque and flexors at
89 two angular velocities (see procedures below). The reliability of these measures was obtained during
90 these two occasions. Visits four, five, six, and seven were intended to carry out the experimental
91 conditions. Perceived recovery was measured before each experimental session. The peak torque of
92 knee extensors and flexors at 90°/s and 120°/s in an isokinetic dynamometer was evaluated before,
93 immediately after the end of each experimental condition, and 30 min later. The rating of perceived
94 exertion (RPE) was measured 30 min after the end of each session. Participants were instructed to
95 avoid the practice of intense physical exercise and alcohol intake 48 h before, avoid caffeine intake six
96 hours before each visit in the laboratory, and were asked to maintain the same eating habits before
97 each of the visits. The tests and experimental protocols were performed in the same sequence and by
98 the same evaluators in the afternoon hours (3 PM to 6 PM).

99 **Participants**

100 The subjects were recruited through social media and personal invitations using the non-probabilistic
101 sampling method yielding 31 volunteers. Three subjects were excluded from the analysis for not
102 having attended the tests and experimental conditions, leaving 28 healthy participants (15 men and 13
103 women, age: 23.6 ± 3.7 years; body mass: 75.9 ± 15.3 kg; stature: 173.6 ± 9.8 cm; body mass index:
104 24.9 ± 2.9 kg/m²; training age: 6.8 ± 3.5 years). The participants were engaged in RT for at least two
105 uninterrupted years, with a weekly frequency of four to six sessions. Subjects were familiarized with
106 measurements and sets of repetitions to failure in the parallel squat exercise before the initiation of the
107 study. Eligible participants had no muscular or joint injury history and did not intake any ergogenic
108 substance for strength and muscle mass in the last six months. Also, the participants were oriented to

109 maintain their routines and eating habits. The participants signed an informed consent term after
110 receiving a detailed description of the study procedures. According to the Declaration of Helsinki, this
111 investigation was conducted and was approved by the local University Ethics Committee (protocol
112 number 2.581.474). The investigation meets the guidelines set forth by the International Journal of
113 Sports Medicine [12].

114 **Perceived recovery**

115 The total quality recovery (TQR) scale [13] was applied before each experimental condition to assess
116 the level of perceived recovery. TQR is a scale that ranges from zero (very poorly recovered/extremely
117 tired) to 10 (very well recovered/highly energetic). The higher the level of perceived recovery is
118 associated with higher values. Participants were familiarized with this scale on visits 1, 2, and 3. The
119 data collected at visits 4, 5, 6, and 7 (days of the experimental conditions) were used for the analyses.
120 Upon arriving at the laboratory, the participants were asked how well they recovered.

121 **Neuromuscular performance**

122 The isokinetic force of knee extension (ISOKext) and flexion (ISOKflex) were assessed at angular
123 velocities of 90°/s and 120°/s at pre-training, immediately post-training, and after 30 min using a
124 Biodex System 4 dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA). The measurements
125 immediately after each experimental condition had a delay of ~60 s due to displacement time from the
126 squat exercise to the isokinetic dynamometer and to adjust their position on the equipment. This
127 measure was analyzed from the peak torque (Nm) of the concentric action of the dominant leg (the
128 preferred used for kicking a ball). According to the anatomical position, participants were placed in a
129 seated position, adjusted based on the manufacturers' recommendations in ~85° of hip flexion. The
130 dynamometer lever arm attachment was aligned with the lateral epicondyle of the femur, and it was
131 secured with straps around the medial malleoli, according to the manufacturer's recommendations.
132 Another strap was placed over the thigh of the participant's dominant leg in the device. Three more
133 straps were placed to keep shoulders, torso, and pelvis stabilized. The total range of motion during the

134 isokinetic test was 90°. Cushing was set as moderate. Gravity correction was performed based on the
135 manufacturer's recommendations. Participants were instructed to put their hands on the shoulders with
136 the arms crossed during the tests and to perform the movement [knee extension (ext) and flexion (flex)]
137 as fast and strong as possible. Three submaximal repetitions at 90°/s were used as familiarization and
138 warm-up. The testing procedure was initiated one minute after the warm-up. Actual testing at each
139 velocity consisted of one set of three repetitions. The participants were notified by a verbal countdown
140 and accompanied by verbal encouragement and visual feedback to ensure maximum effort. Also,
141 participants were coached to exert maximal effort using incentive phrases such as “force up,” “force
142 down,” “go faster and stronger,” accompanied by clapping. The rest intervals were 2-min between
143 different angular velocities. The maximum value of peak torque in each muscle action and velocities
144 (ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex) was obtained and used in analyses. The
145 tests were performed in the same sequence and by the same evaluator in the afternoon (3 PM to 6 PM).
146 These procedures were repeated on two non-consecutive days, at least 48 hours apart.

147 **Resistance training sessions**

148 The exercise performed was the parallel back squat using free weights. All participants performed the
149 15RM test in two sessions separated by 48 h to determine the RT loads for experimental protocols.
150 The procedures for this test are described in more detail in Kassiano et al. [3]. The resistance training
151 sessions were planned to equalize the volume-load. Therefore, the participants had to complete 60
152 repetitions for the same relative intensity (15RM) in all conditions. The experimental protocols were
153 different regarding the resistance training configurations, namely: (i) IRR, 60 repetitions interspersed
154 with ~10 s of rest in between them; (ii) TRD, five sets with 12 repetitions (~3 repetitions in reserve),
155 with 180 s of rest interval; (iii) TRD-F, four sets of 15 repetitions with 200 s of rest interval between
156 sets; and (iv) RP, blocks of repetitions performed until concentric muscle failure (i.e., inability to
157 complete a repetition with a full range of motion and proper technique [6, 8]) and 30 s of rest interval
158 between them, until the completion of 60 repetitions. The participants were instructed to perform the

159 repetition tempo at a ratio of 1:2 (concentric and eccentric muscular actions, respectively). The four
160 experimental conditions were carried out in a randomized and counterbalanced order with a seven-day
161 washout between each one. The number of repetitions in each set was recorded. The volume-load of
162 the experimental sessions was calculated from of product between the number of repetitions and load
163 lifted. The configuration of each experimental condition is illustrated in **Fig. 1**.

164 ***** PLEASE INSERT FIG. 1 NEAR HERE *****

165 **Rating of perceived exertion**

166 The OMNI-RES scale [14] was used to obtain the RPE from the experimental sessions. All volunteers
167 were submitted to two sessions (visits 2 and 3) for the RPE anchoring procedures. The leading
168 investigator explained to each participant what each descriptor in the OMNI-RES scale represents
169 according to the procedures proposed by Robertson et al. [14]. The RPE was obtained 30 min after the
170 end of each experimental condition through the following question: “How (hard) was your training?”.
171 Participants were asked to indicate a score corresponding to perceived exertion experienced during
172 each of the four experimental sessions (IRR, TRD, TRD-F, and RP) in visits 4, 5, 6, and 7. The same
173 investigator carried out this procedure during all sessions. Each participant's response was obtained
174 without any other observer to reduce the chances of having effects of external factors on the RPE
175 response.

176 **Statistical analyses**

177 The Shapiro-Wilk test was used to evaluate the data distribution. The data are presented
178 through mean and confidence intervals (95% CIs). Repeated-measures analysis of variance (ANOVA)
179 was used to compare the level of perceived recovery, RPE, and volume-load between the experimental
180 conditions. A two-way repeated-measures ANOVA was used to analyze the conditions (IRR, TRD,
181 TRD-F, and RP) x time (pre, post, and post-30min) interaction for isokinetic strength measures
182 (ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex). When sphericity was violated, the
183 Greenhouse-Geisser correction factor was applied. When the F was significant, a Bonferroni post hoc

184 test was used to identify possible statistical differences. We adopted the effect size (ES) of the model
185 [partial eta squared (η^2)]. In addition, we calculated the ES (Cohen's d_z) proposed by Dankel and
186 Loenneke [15] for comparisons pre to post and pre to post-30 min. In addition, we carry out a
187 secondary analysis based on the relative changes ($\Delta\% = [(post - pre) / pre] \times 100$). We compared the
188 $\Delta\%$ (pre vs. post and pre vs. post-30 min) of the extensors vs. knee flexors within each condition
189 through a two-way ANOVA with muscle action (extension and flexion) and angular velocities as fixed
190 factors. Significance was accepted at $P < 0.05$.

191 Results

192 For the 15RM test, the $ICC_{3,1}$, coefficient of variation (CV), and standard error of measurement
193 (SEM) were: $ICC_{3,1} = 0.97$ (0.94, 0.98), $CV = 3.5\%$, and $SEM = 0.58$ kg. Test-retest reliability of force
194 measures, for namely ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex yielded an $ICC_{3,1}$
195 (95% CI) of 0.98 (0.97, 0.99), 0.93 (0.86, 0.96), 0.97 (0.95, 0.99), and 0.97 (0.94, 0.98), respectively;
196 CV of 3.9%, 4.5%, 3.6%, and 3.1%, respectively; and SEM of 0.65, 2.64, 1.89, and 0.83 Nm,
197 respectively.

198 The total ~781s, 900s, 780s, and 761s, IRR, TRD, TRD-F, and RP, respectively. The TQR,
199 number of repetitions, volume-load, and RPE data are shown in **Table 1**. There were no significant
200 differences between the four conditions for the TQR ($F_{(3, 69)} = 0.472$, $P > .05$, $\eta^2 = 0.01$), number of
201 repetitions performed in each experimental session ($F_{(1.0, 24.0)} = 1.080$, $P > .05$, $\eta^2 = 0.04$), and volume-
202 load ($F_{(1.0, 27.0)} = 0.717$, $P > .05$, $\eta^2 = 0.02$). A significant main effect ($F_{(3, 78)} = 75.903$, $P < .001$, η^2
203 $= 0.74$) was revealed only for RPE. The IRR configuration presented lower RPE than the TRD (95%CI:
204 -1.3, -0.0, $P = .046$), TRD-F (95%CI: -3.7, -2.1, $P < .001$) and RP (95%CI: -4.2, -2.8, $P < .001$)
205 configurations. The TRD configuration had lower RPE scores when compared to the TRD-F (95%CI:
206 -3.1, -1.4, $P < .001$) and RP (95%CI: -3.7, -1.9, $P < .001$).

207 *** PLEASE INSERT TABLE 1 NEAR HERE ***

208 The peak torque data for the two muscular actions (knee extension and flexion) at the two
 209 angular velocities (90°/s and 120°/s) from the four resistance training configurations are described in
 210 **Table 2**. There was a significant interaction ($F_{(3.7, 82.9)} = 11.647, P < .001, \eta^2 = 0.34$) for the
 211 ISOK90ext. In the IRR condition, there were no significant changes among the three moments ($ES \leq$
 212 $-0.51, P > .05$). The ISOK90ext was significantly lower at post in the TRD ($ES = -1.42, P < .001$),
 213 TRD-F ($ES = -1.27, P < .001$), and RP ($ES = -1.62, P < .001$). At post-30 min, the peak torque of
 214 ISOK90ext remained suppressed in the TRD ($ES = -1.37, P < .001$), TRD-F ($ES = -1.26, P < .001$),
 215 and RP ($ES = -1.21, P < .001$) when compared to the pre; without significant differences between post
 216 and post-30 min (Table 2). About the differences between configurations, the ISOK90ext was
 217 significantly lower in TRD ($P = .004$), TRD-F ($P = .001$), and RP ($P < .001$) configurations when
 218 compared to IRR (**Fig. 2**). This scenario remained relatively stable post-30 min, the ISOK90ext
 219 remained lower in the TRD ($P = .002$), TRD-F ($P < .001$) and RP ($P = .001$) when compared to the
 220 IRR.

221 *** PLEASE INSERT TABLE 2 NEAR HERE ***

222 *** PLEASE INSERT FIG. 2 NEAR HERE ***

223 For ISOK90flex, there was a main effect of time ($F_{(1.2, 26.9)} = 36.955, P < .001, \eta^2 = 0.62$) and
 224 condition ($F_{(2.0, 45.1)} = 22.400, P < .001, \eta^2 = 0.50$). In the IRR condition, there were no significant
 225 changes between any of the three moments ($ES \leq -0.39, P > .05$). The ISOK90flex was significantly
 226 lower at post in the TRD ($ES = -1.37, P < .001$), TRD-F ($ES = -1.18, P < .001$), and RP ($ES = -1.13,$
 227 $P < .001$). At post-30 min, the ISOK90ext remained suppressed in the TRD ($ES = -1.14, P < .001$),
 228 TRD-F ($ES = -1.23, P < .001$), and RP ($ES = -0.99, P < .001$) when compared to the pre; without
 229 significant differences between post and post-30 min (**Table 2**).

230 Regarding ISOK120ext, there was a significant interaction ($F_{(3.2, 71.4)} = 15.891, P < .001, \eta^2 =$
 231 0.41). In the IRR condition, there were no significant changes between any of the three moments (ES
 232 $\leq -0.52, P > .05$). The ISOK120ext was significantly lower at post in the TRD ($ES = -1.27, P < .001$),

233 TRD-F (ES = -1.40, $P < .001$), and RP (ES = -1.47, $P < .001$). At post-30 min, the peak torque of
 234 ISOK120ext remained suppressed in the TRD (ES = -1.28, $P < .001$), TRD-F (ES = -1.41, $P < .001$),
 235 and RP (ES = -1.66, $P < .001$) when compared to the pre; without significant differences between post
 236 and post-30 min (**Table 2**). When comparing configurations, ISOK120ext in TRD was significantly
 237 lower than IRR ($P = .029$) and higher than RP ($P = .026$) at post. TRD-F and RP also showed lower
 238 ISOK120ext ($P = .008$; $P < .001$, respectively) values when compared to IRR. In the post-30min, the
 239 conditions TRD ($P < .001$), TRD-F ($P = .001$) and RP ($P < .001$) showed lower ISOK120ext than IRR.

240 For ISOK120flex, there was also a main effect of interaction ($F_{(2,3, 52,5)} = 6.323$, $P = .002$, η^2
 241 = 0.22). There were no significant changes between the three moments in the IRR (ES \leq -0.33, $P >$
 242 .05). The ISOK120flex decreased at post in the TRD (ES = -0.72, $P = .005$), TRD-F (ES = -1.18, $P <$
 243 .001), and RP (ES = -1.61, $P < .001$). At post-30 min, the peak torque of ISOK120flex in the TRD had
 244 returned to pre values (ES = -0.26, $P > .05$); on the other hand, remained suppressed in the TRD-F (ES
 245 = -0.95, $P < .001$), and RP (ES = -1.80, $P < .001$) when compared to the pre; without significant
 246 differences between post and post-30 min (**Table 2**). Regarding to comparisons between
 247 configurations, the ISOK120flex in the post was significantly lower in TRD ($P = .007$), TRD-F ($P =$
 248 .012) and RP ($P < .001$) when compared to IRR. At the post-30min, ISOK120flex in TRD was
 249 significantly higher than RP ($P = .027$). TRD-F and RP also showed lower ISOK120flex ($P = .006$; P
 250 $< .001$, respectively) values when compared to IRR (**Table 2 and Fig. 2**).

251 From the secondary analysis, we observed that the relative changes ($\Delta\%$) were not different at
 252 both angular velocities immediately after the four conditions when comparing peak torque of knee
 253 extension versus knee flexion (all $P > 0.05$). At post-30 min, the behavior was similar for all
 254 experimental conditions, except the TRD condition for muscular actions at 120°/s. The decrease in
 255 ISOK120ext was significantly greater [$\Delta\% = -15.9$ (95%CI: -21.1, -10.7)] than the decrease in
 256 ISOK120flex [$\Delta\% = -3.8$ (95%CI: -9.0, 1.4)] at post-30 min ($P = .001$).

257 Discussion

258 The main findings of our study were: (i) the neuromuscular performance of knee extensors and flexors
259 was attenuated in response to TRD, TRD-F and RP, and remained decreased 30-min after the end these
260 experimental protocols; (ii) the IRR configuration allowed the maintenance of performance even with
261 a volume-load similar to the other resistance training configurations; (iii) the relative reduction in
262 performance was similar between extensors (quadriceps) and flexors (hamstrings) after all
263 experimental protocols at the two angular velocities; (iv) after 30-min of the TRD protocol, the
264 decrease in the isokinetic force of the quadriceps was higher than the reduction in the isokinetic
265 strength of the hamstrings at 120°/s; and (v) the TRD-F and RP caused higher RPE, followed by TRD
266 and IRR configurations, respectively.

267 In the present study, the IRR configuration was an effective strategy to maintain the
268 neuromuscular performance of the knee extensors and flexors after performing the parallel back squat.
269 In fact, in a meta-analysis, the authors demonstrated that the IRR and intra-set rest (commonly
270 characterized as types of cluster sets) configurations acutely reduced velocity and power throughout
271 the sets [4]. These configurations seem to be effective because the accumulation of metabolites is
272 avoided, and fatigue dissipation is favored [7]. In addition, it makes it possible to achieve a high
273 volume-load without deleterious effects on neuromuscular performance [4]. In turn, this higher volume
274 can potentially be converted into greater strength gains [9, 10]. However, these benefits are not
275 universal. For example, the force output was similar between the IRR and intra-set rest and TRD
276 configuration [4], suggesting that responses may depend, at least in part, on the performance variable
277 being measured (power output or force output).

278 On the other hand, the RP configuration (another type of cluster set) [4] induced a reduction in
279 force production that lasted up to 30-min after the end of the resistance training protocol. Differently,
280 the IRR configuration has been less investigated concerning acute responses of neuromuscular
281 performance [4, 7], and only one study on the RP configuration was included in the recent meta-
282 analysis about the topic [4]. In this investigation, Marshall et al. [6] reported that the force output was

283 suppressed shortly after the squats. However, five minutes later, the force parameters had already
284 returned to the baseline values [6]. A possible explanation for such a divergence between our findings
285 and those of Marshall et al. [6] may be the number of repetitions/volume-load performed in each study.
286 For example, in the present study, participants performed 60 repetitions, while those of Marshall et al.
287 [6] completed 20 repetitions. Therefore, under conditions of greater volume-load, the RP seems to be
288 more harmful to the neuromuscular performance of both muscle groups (quadriceps and hamstrings).

289 Regarding the TRD-F and TRD configurations, both reduced the force output immediately after
290 the end of the session for the two muscular actions and angular velocities tested. However, while these
291 measures remained attenuated after 30-min in the TRD-F protocol, the flexors' peak torque at 120°/s
292 returned to the baseline values in the TRD. Together, these findings can be interpreted as follows: (a)
293 performing multiple sets to or near to voluntary muscle failure induce reductions in neuromuscular
294 performance in trained subjects [16-18]; (b) to perform the exercise close to failure in most sets (a fact
295 that occurred in the TRD), even with high volume-load, can be harmful the force production, since the
296 peak torque of the flexors returned to baseline values 30-min after the TRD condition. However,
297 further investigations are needed to characterize the time-course, this possible difference, and how
298 many repetitions in reserve are necessary to the strength return to baseline values quickly.

299 Our results revealed that both quadriceps and hamstrings experienced a similar performance
300 reduction. Therefore, our hypothesis was not confirmed. Because the quadriceps are the agonist group
301 in the parallel back squat exercise and supported by previous studies [19-21], we believed that this
302 muscle group would significantly reduce the peak torque. However, except for the ISOK120flex,
303 which flexors showed less reduction compared to the extensors in the TRD, all other responses were
304 similar between quadriceps and hamstrings. This finding might be explained by the fact that the
305 exercise chosen for the present study involves many muscle groups [19], depending on the applied
306 effort (that was high in the conditions that reduced the force) [22, 23]. This phenomenon affects the
307 overall strength production and not only of the agonist muscles [22]. Another factor that may have

308 contributed to such responses may be the role of antagonistic exercised by the hamstrings that act in
309 co-contraction during the squat [19].

310 To the best of our knowledge, our study was the first to investigate the effects of different
311 resistance training configurations on the knee extensors and flexors' neuromuscular performance and
312 compare these effects between quadriceps and hamstrings muscle groups. Some strengths of the
313 present study deserve mention. The randomized, counterbalanced, cross-over design, with washout
314 and equalized volume-load, allows accurately analyzing the impact of different resistance training
315 configurations on neuromuscular performance. Also, the measurement of force output was performed
316 using an isokinetic dynamometer, which is commonly pointed out as the gold standard instrument for
317 this purpose. In contrast, some limitations should not be ignored. The present study was conducted
318 with a single multi-joint exercise (parallel back squat), and our sample was composed of trained
319 subjects. Therefore, the information in this investigation must be interpreted with caution and applied
320 in a similar context. Another significant limitation is the fact that we did not follow up neuromuscular
321 performance hours after each condition. Such information could show us how long it would take to
322 restore performance after each resistance training configuration. Finally, we did not measure the
323 velocity component in the present study; therefore, future investigations should consider measuring
324 this characteristic to describe the effects of different configurations on neuromuscular performance
325 and include force tests at higher speeds (e.g., 180°/s and 300°/s).

326 **Conclusion**

327 From a practical standpoint, strength and conditioning coaches and resistance training
328 practitioners who seek to maintain neuromuscular performance after a training session are encouraged
329 to use the IRR configuration, as this set configuration does not reduce the force production of the knee
330 extensors and flexors, even after performing 60 repetitions on the parallel back squat. Conversely,
331 when using TRD, TRD-F, and RP configurations, the performance of lower limbs likely be decreased
332 for at least 30 min after the resistance training session; and this will require trainers to monitor the

333 performance of their athletes before applying a new training session. Additionally, although the squat
334 is an exercise that primarily involves the actions of hip and knee extension in the concentric phase,
335 which in theory, would require more considerable effort in the quadriceps when compared to the
336 hamstrings, the reduction in performance occurs in a similar way between these two muscle groups.

337

338 **Conflict of interest**

339 The authors report no conflicts of interest.

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392

393 **TABLE LEGENDS**

394 **Table 1.** State of recovery, performance, and perceived effort in the four experimental conditions (n
395 = 28).

396 *Note.* The data are presented in mean and 95% CI; TQR = total quality recovery; AU = arbitrary units; RPE = rating of
397 perceived exertion; IRR = inter-repetition rest configuration; TRD = traditional system not to failure; TRD-F =
398 traditional configuration to failure; RP = rest-pause; * different from IRR; † different from TRD.

399 **Table 2.** The isokinetic force of knee extensors and flexors at two angular velocities at pre,
400 immediately post, and post-30min each experimental condition (n = 28).

401 *Note.* The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional
402 configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to
403 pre; † different when compared to IRR; ‡ different when compared to TRD.

404

405 **FIGURES LEGENDS**

406 **Fig. 1.** Resistance exercise sessions.

407 *Note.* rep = repetitions; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F =
408 traditional configuration to failure; RP = rest-pause.

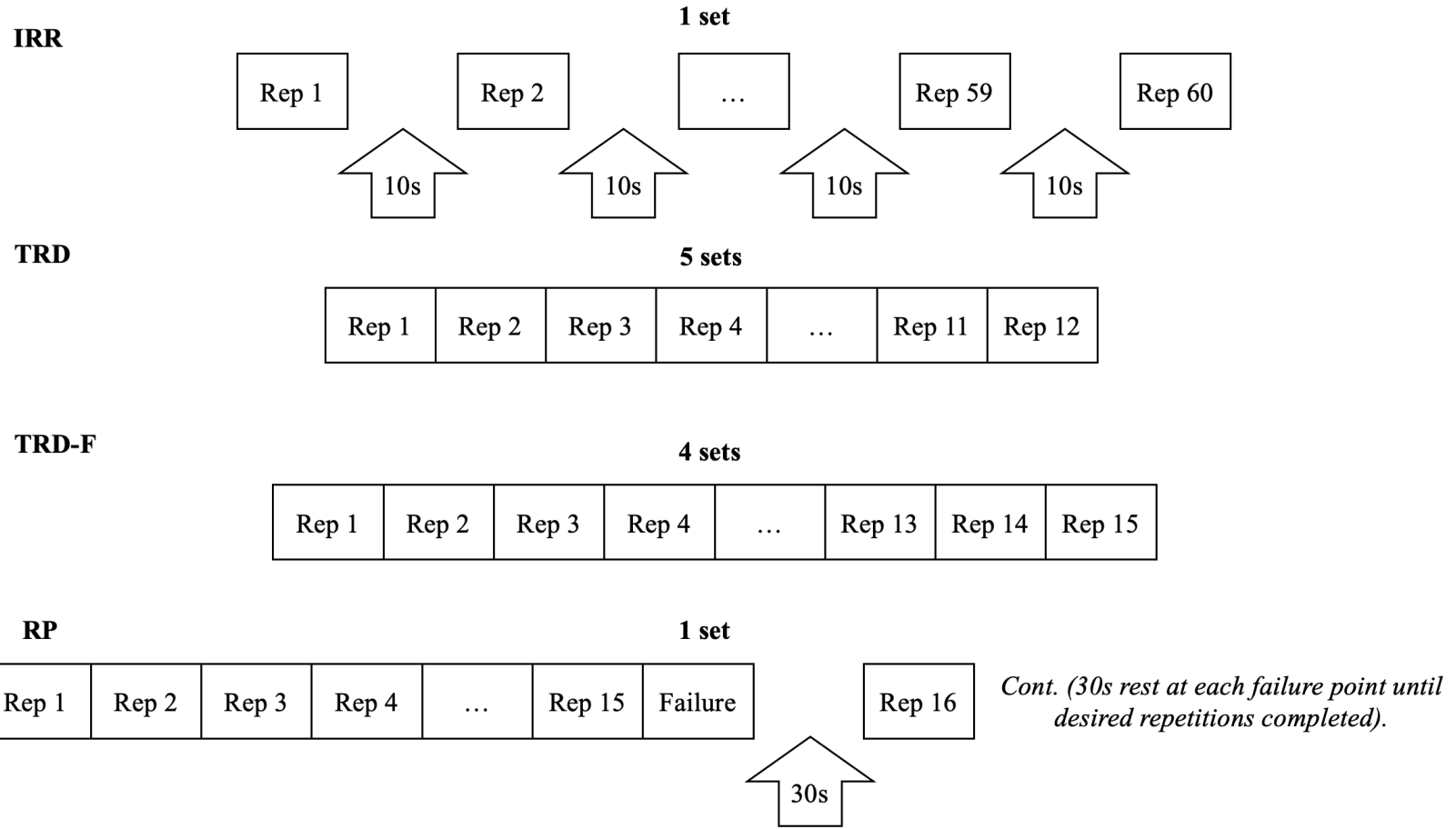
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410 **Fig. 2.** Relative changes for the isokinetic force of knee extensors and flexors at both velocities are in
411 the four experimental conditions (n = 28).

412 *Note.* The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional configuration
413 not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to pre; † difference
414 between conditions in the post; ‡ difference between conditions at post-30min.

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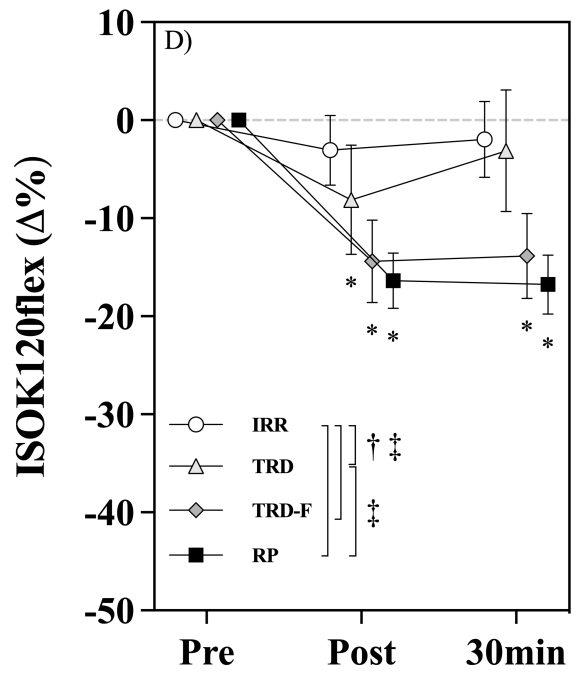
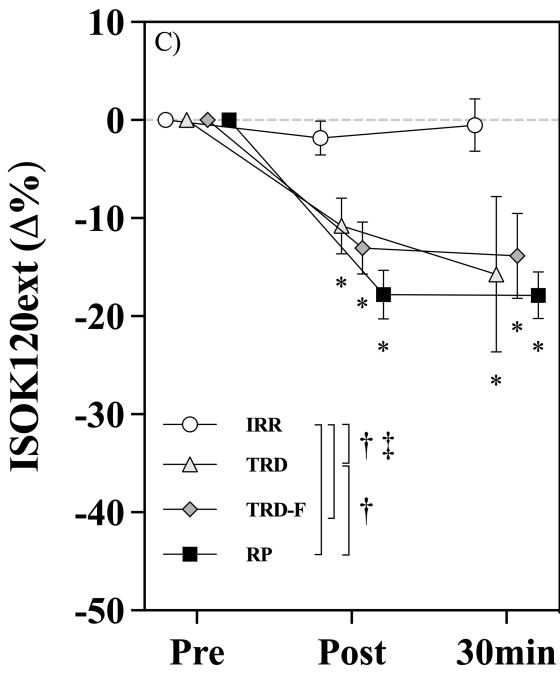
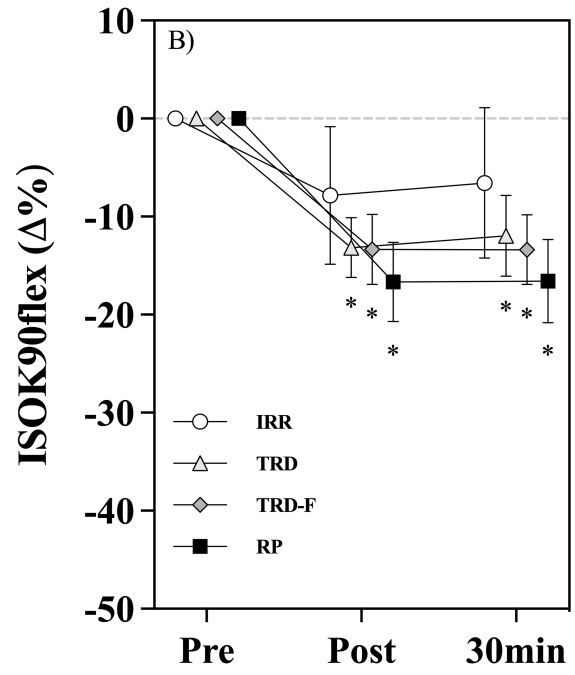
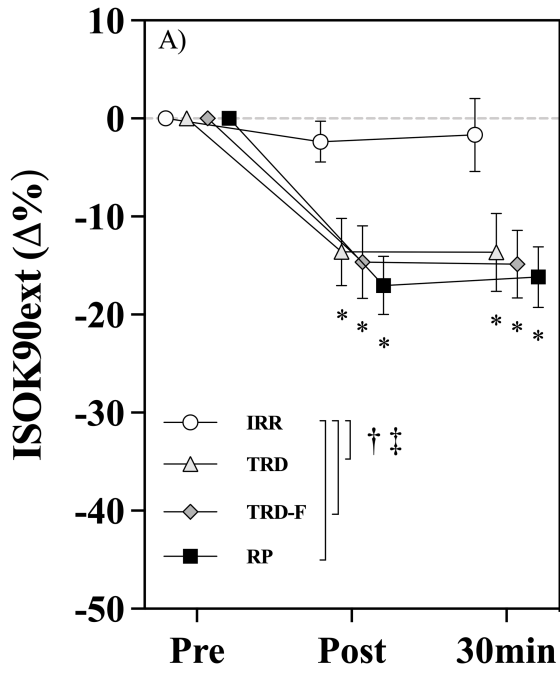


Table 1. State of recovery, performance, and perceived effort in the four experimental conditions (n = 28).

	Conditions			
	IRR	TRD	TRD-F	RP
TQR (AU)	8.9 (8.5–9.4)	8.6 (8.1–9.0)	8.7 (8.2–9.2)	8.8 (8.3–9.3)
N° of repetitions	60.0 (60.0–60.0)	60.0 (60.0–60.0)	58.8 (56.4–61.1)	60.0 (60.0–60.0)
Volume-load (kg)	3340 (2695–3984)	3340 (2695–3984)	3279 (2636–3922)	3340 (2695–3984)
RPE (AU)	5.3 (4.9–5.7)	6.0 (5.5–6.5)*	8.2 (7.8–8.7)*†	8.8 (8.5–9.1)*†

Note. The data are presented in mean and 95% CI; TQR = total quality recovery; AU = arbitrary units; RPE = rating of perceived exertion; IRR = inter-repetition rest configuration; TRD = traditional system not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different from IRR; † different from TRD.

Table 2. The isokinetic force of knee extensors and flexors at two angular velocities at pre, immediately post, and post-30min each experimental condition (n = 28).

Measures		Conditions			
		IRR	TRD	TRD-F	RP
ISOK90ext (Nm)	Pre	239.5 (204.8–274.1)	241.4 (207.0–275.9)	241.4 (206.7–276.0)	238.7 (203.8–273.7)
	Post	233.2 (199.6–266.7)	207.8 (179.0–236.6)*†	205.7 (176.1–235.3)*†	199.0 (168.4–229.6)*†
	Post-30min	233.7 (200.3–274.1)	207.4 (178.4–236.3)*†	204.9 (175.5–234.2)*†	201.3 (170.3–232.3)*†
ISOK90flex (Nm)	Pre	138.8 (114.1–163.6)	123.5 (107.6–139.4)	125.0 (108.6–141.4)	122.6 (106.9–138.2)
	Post	121.2 (106.0–136.4)	105.7 (93.7–117.8)*	106.7 (93.9–119.5)*	101.8 (88.3–115.3)*
	Post-30min	122.0 (106.0–137.4)	106.7 (94.6–118.9)*	107.0 (93.7–120.3)*	101.6 (88.6–114.6)*
ISOK120ext (Nm)	Pre	221.6 (188.9–254.4)	224.6 (191.5–257.7)	224.1 (191.7–256.6)	224.8 (191.3–258.2)
	Post	216.6 (185.5–247.8)	198.6 (171.3–226.0)*†	196.3 (166.3–226.0)*†	185.0 (156.3–213.6)*†‡
	Post-30min	219.0 (187.7–250.3)	191.7 (159.5–223.8)*†	196.7 (167.1–226.3)*†	185.1 (156.3–213.9)*†
ISOK120flex (Nm)	Pre	126.1 (112.7–139.5)	122.7 (109.8–135.7)	126.6 (114.2–139.0)	124.2 (111.1–137.4)
	Post	121.1 (109.7–132.5)	111.4 (100.8–122.0)*†	108.4 (96.2–120.5)*†	102.9 (93.3–112.6)*†
	Post-30min	122.2 (111.0–133.4)	118.4 (104.7–132.2)	109.0 (96.8–121.2)*†	102.5 (92.7–112.2)*†‡

Note. The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to pre; † different when compared to IRR; ‡ different when compared to TRD.